MILLIMETER-WAVE SELF MIXING OSCILLATORS

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INTRODUCTION

The self-mixing oscillator has been of considerable interest in recent years (1)-(3) because it embodies simplifications for the circuitry of electronic systems. Schottky barrier and other rectifier diodes suffer from the disadvantage of fragility and low burn-out power limit. Bulk effect self-oscillating mixers using the non-linearity of transferred electron (GUNN) devices offer competitive sensitivities and the attractive feature of high power handling capability.

Conventional mixers, ususally consist of a mixer diode of the rectifier type and a separate local oscillator. In the self-oscillating mixer, the mixer diode is eliminated, the Gunn diode (or BARITT diode) serving both as a local oscillator, and because nonlinearities are always present in an oscillator, as a mixing element. With the Gunn diode oscillator serving both these functions, the integrated receiver front-end design using the dielectric image guide approach becomes extremely compact and simplified. In the latter arrangement, the signal is fed directly into the oscillator and a suitable IF probe removes the IF signal power for use in subsequent amplifier stages. What makes self-oscillating mixing different intrinsically from the conventional mixing process with a passive device (such as the Schottky junction diode) is that self-mixing occurs with conversion gain (rather than loss) similar to parametric amplification, (1), (3).

One of the objectives of this work was the design of self-oscillating mixers with considerable simplification, with the attendant

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reductions in cost. In the quest for lower cost, the dielectric wave-
guide (or image-line) technology was applied using a Gunn diode, in a
simply constructed cavity, in a self-excited oscillator-mixer mode of
operation. Both GaAs and InP Gunn diodes were imbedded in an aper-
ture which was cut in a high resistivity aluminum oxide dielectric
waveguide. The significance of the dielectric waveguide technology is
that active devices, as well as passive components, can be developed
and integrated into circuit modules to construct functional subsystems.

DEVICE DESIGN

The metal waveguide self-mixing oscillator utilizing a coax-
waveguide hybrid circuit is shown in Fig. 1. The packaged diode is
imbedded in a copper heat sink at the end of a coaxial line section.
A large section of the outer conductor is removed with the removed
section facing the waveguide opening to form a broad-band coaxial-to-
waveguide transition. A wide-band choke terminates the opposite end
of the line. The dc bias to the Gunn diode and extraction of the IF
signal is also provided at this end. The dielectric waveguide oscil-
lator cavity design is based on an image-line concept first formulated
by Marcatili (4) and modified for millimeter-waves (5), (6). The
fundamental electromagnetic wave propagating in a dielectric waveguide
is the E_{11}^y mode, a hybrid mode which propagates when correctly launch-
ed. Theory indicates that the dielectric waveguide for proper opera-
tion should be on the order of one wavelength in the medium in width,
and less than one-half wavelength in height. At 60 GHz, cross-section-
al dimensions of the dielectric guides were oversized, i.e., slightly
greater than 1 millimeter in height and about 2 millimeters in width.
Experiments indicated that in this oversized condition, the E_{11}^y mode
dominated. The resonant length of the dielectric section in back of
the diode chosen for optimum power, was approximately $(2n+1)\lambda/2$ in
length.

A simplified schematic of the self-oscillating mixer (Fig. 2)
shows the manner of coupling to the metal waveguide; note that one
end of the resonant cavity is tapered. The dielectric image guide
taper can effect a low loss match to the metal waveguide by sliding
the tapered end into the metal waveguide for maximum power transfer.
This matching condition also yielded optimum IF output when the RF
input signal was introduced. Fig. 3 gives a more detailed cut-away
view of the device investigated; the IF exits out of the top of the
dielectric guide with a metal disc being used as a matching element
from the Gunn diode to the dielectric waveguide. Fig. 4 shows an
exploded view of a 60 GHz dielectric waveguide self-oscillating
mixer which utilizes a tuneable short to optimize performance; Fig. 5

shows the same unit ready for operation.

Referring to Fig. 4, the metal housing was designed for minimum radiation leakage with dimensions that were oversized with respect to WR-15 waveguide. The Gunn diode is mounted flush with the bottom of the metal structure. The aluminum oxide dielectric waveguide with tapered front end was bonded to the metal housing in such a way that the Gunn diode tip protruded up into the dielectric. A 0.045" hole in the dielectric waveguide allowed the IF and bias voltage post to come down and make a pressure contact with the top of the Gunn diode. This method of applying the bias voltage made it possible to mount a tuning short behind the dielectric guide.

EXPERIMENTAL RESULTS

Fig. 6 shows the output power and frequency characteristics of an InP diode in a waveguide cavity as a function of the bias voltage. Note that the frequency can be tuned over a range of 280 MHz with a change of bias of 1.2 volts; this change in bias voltage gave a change in output power from 19 to 23 mW. Similar characteristics were obtained with the GaAs Gunn diode in a waveguide cavity except that the peak bias voltage was in the order of 4.5 volts with peak powers of 6.5 mW. These peak output powers are typical of those used in the self-mixing experiments.

In the quest for a much lower cost device, GaAs and InP Gunn diodes were imbedded in an image guide cavity structure and their performance evaluated. This is the first time InP Gunn diodes have been evaluated as self-mixing oscillators either in metal waveguides or image line configurations. Figure 7 shows the output power and frequency characteristics of a GaAs diode as a function of the bias voltage. Figure 8 shows the same information using an InP diode. It should be noted that the bias voltage on the InP diode required for oscillation occurs at a higher value than that of the GaAs diode. The output powers are typical of those used in the self-mixing experiments. Figure 9 shows a block diagram of the RF circuit used in evaluating the two types of self-mixing Gunn oscillators. A backward wave oscillator in a mechanically tuneable mode was used as the signal source. The single frequency output from this source was stable within +0.001% with non-harmonic spurious signals recorded 40 dB down. This very stable signal was tuned 60 MHz above or below the Gunn oscillator frequency to produce the IF frequency.

The difference signal at 60 MHz was displayed on the face of a spectrum analyzer oscilloscope. By increasing the attenuation in

the signal channel, the IF energy could be made to decrease and disappear into the noise level of the spectrum analyzer. The attenuation was then decreased until the detected IF power was 3 dB above the noise level. At this point, the signal level was equal to the noise level and this IF power was defined as the minimum detectable signal power measured in decibels referred to 1 mW. The oscillating diode was tuned by the bias voltage just above the threshold field and also by the RF circuit to achieve the desired operating point. Care was taken to insure that no spurious oscillation or bias circuit instabilities were present.

The amplitude of the IF power in dBm was compared with measured values of input signal power for conversion gain or loss measurements. Figure 10 shows the IF output power as a function of signal power input for a GaAs Gunn diode. Figure 11 shows the same information for a InP Gunn diode. On both figures the last data point at the lowest power level indicates the noise reference level. The minimum detectable signal is defined as 3 dB higher and is shown in the next higher point of the figure. Note that the GaAs and InP Gunn diodes have a minimum detectable signal in the order of -77 and of -81 dBm respectively. This minimum detectable power is the principle parameter for determining the sensitivity of a self-mixing oscillator. It indicates how weak a signal the device can detect. Figure 12 shows the conversion gain measured on the GaAs Gunn oscillator. Figure 13 shows the same information for an InP Gunn self-mixing device; note that the conversion gain increases as the signal-input power decreases. The conversion efficiency as a function of bias voltage, with the signal held constant, is shown in Figure 14; the conversion gain peaks at a bias voltage just above the threshold voltage for oscillation. This behavior is consistent with information reported previously by investigators at lower frequencies using GaAs Gunn diodes in waveguide cavities.

DISCUSSION OF RESULTS

In terms of sensitivity, the data indicates that the InP self-mixing oscillator's performance is better than that of the GaAs device. This seems to verify the fact that InP is a superior material in several respects. It has a current peak-to-valley ratio of 3.5 as opposed to 2.5 for GaAs (7); this, in theory, will provide higher oscillator conversion efficiencies. In addition, the peak-to-valley ratio degrades less rapidly with temperature operation (7). The peak conversion gain was found to be approximately 10 dB for the InP device and 5 dB for the GaAs self-mixing device. Similar gain characteristics has been reported by several investigators for gallium arsenide when the diode is operated at voltages just above

threshold (1), (3). We conclude that InP diodes have higher conversion gain and hence lower noise.

An outstanding characteristic of the self-mixing oscillator is that the sensitivity or conversion gain increases as the signal level decreases. This characteristic has also been reported in the literature by investigators working at 34 GHz (1).

The principal design thrust for this program was the quest for a low weight, low cost device with simple construction. The dielectric image line approach has been shown to be well suited to accomplishing these objectives. The high sensitivities of -77 dBm for GaAs and -81 dBm for InP self-mixing oscillators makes these devices very attractive for the mixer function in certain applications.

CONCLUSION

It has been shown that, using GaAs and InP diodes imbedded in dielectric waveguide in simplified design principals given here, self-mixing Gunn oscillators of different operating voltages and frequencies can be successfully designed. Experimental data indicates that the sensitivity of these devices are in the order of -80 dBm which would make them competitive with other conventional mixers. However, these devices have the advantage of having simplified construction with a high signal power burnout level coupled with very low unit cost. These characteristics make the self-mixing oscillator a viable device in low cost receivers, expendable EW sensors, and short range terminal guidance. In addition, the InP self-mixing device has great potential in the higher millimeter-wave frequency region (above 100 GHz) due to its higher effective transit velocity and fast inter-valley scattering.

ACKNOWLEDGEMENTS

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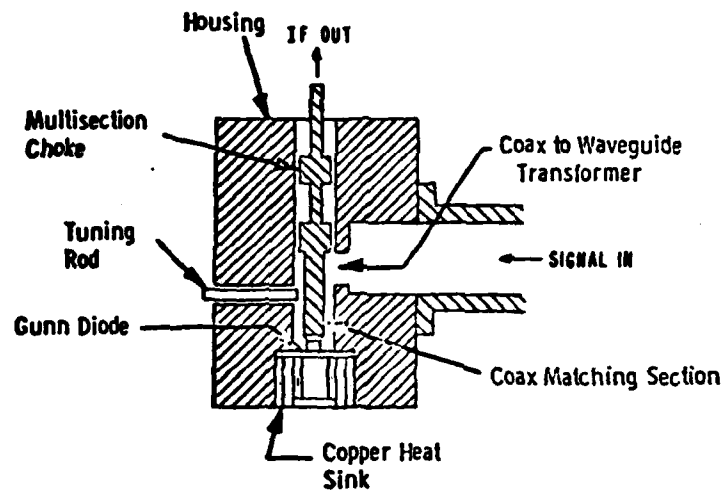
Fig. 1 Cutaway view of waveguide self-oscillating mixer.
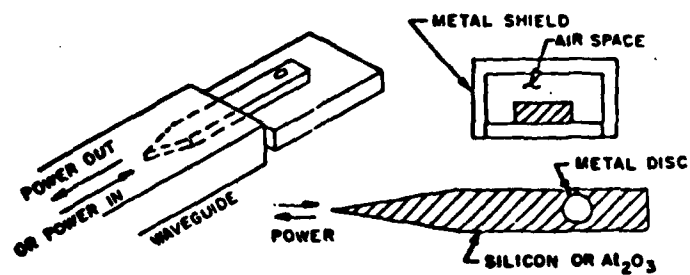
Fig. 2 Image guide mixer coupling to waveguide.
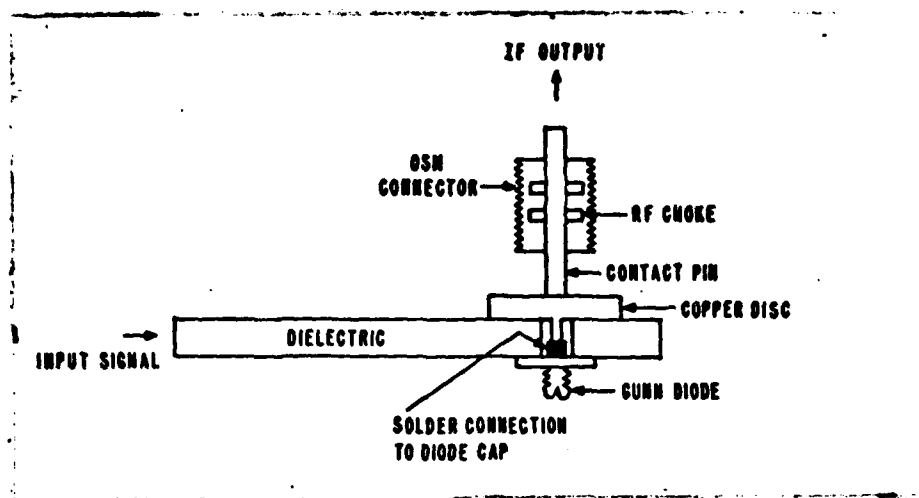
Fig. 3 Cutaway view of image guide
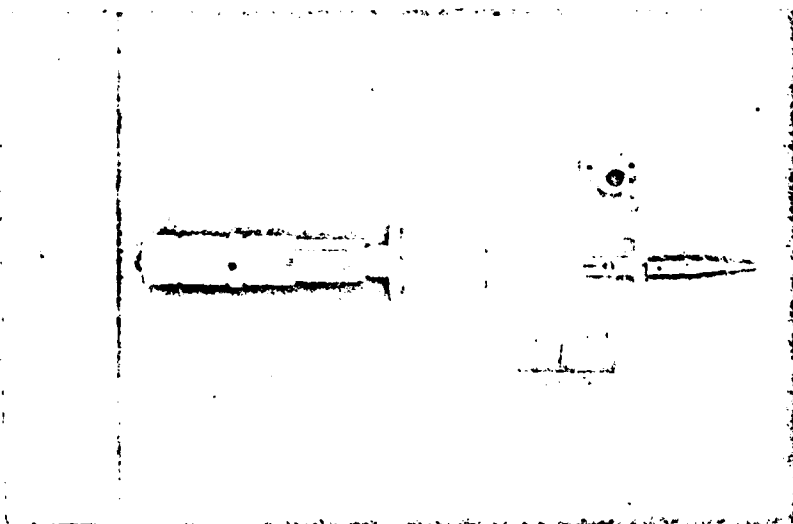self-oscillating mixer.

Fig. 4 Exploded view of image guide
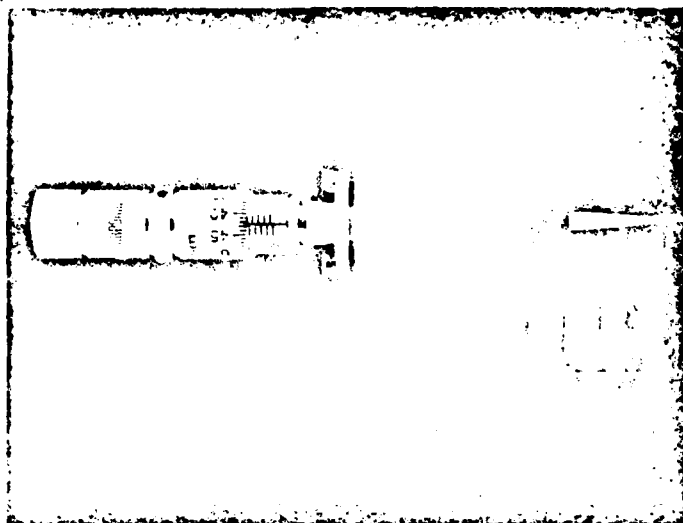self-oscillating mixer.

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Fig. 5 Assembled image guide
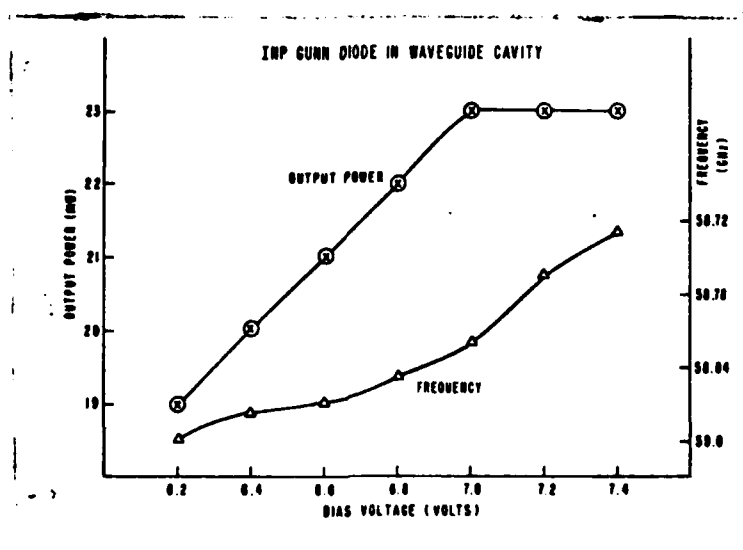self-oscillating mixer.

Fig. 6 Characteristics of InP waveguide
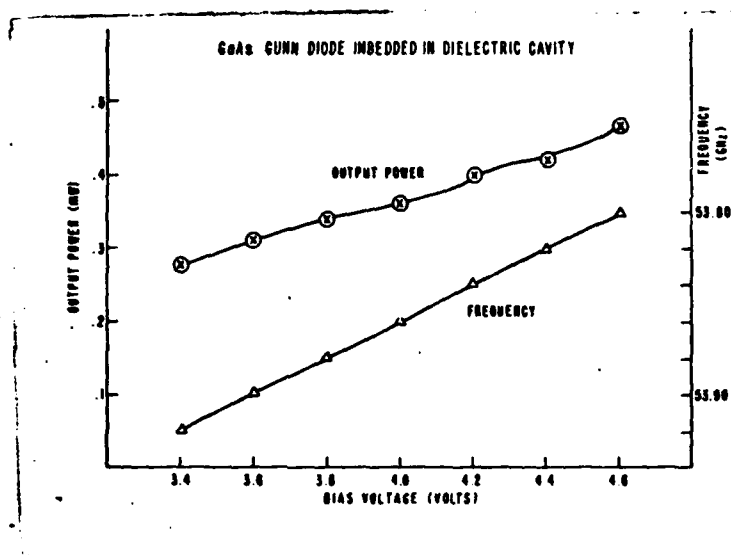cavity oscillator.

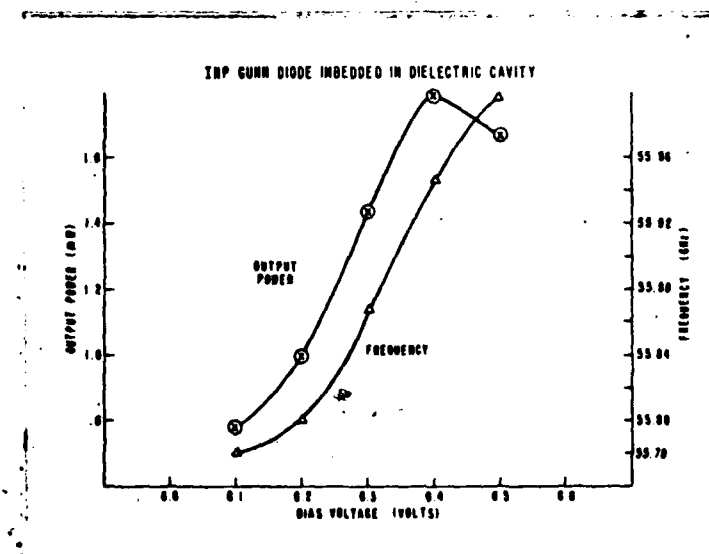**Fig. 7 Characteristics of GaAs image guide oscillator.**

Fig. 8 Characteristics of InP image guide oscillator.

BLOCK DIAGRAM OF MILLIMETER-WAVE SYSTEM USED IN MEASUREMENTS OF
MINIMUM DETECTABLE SIGNAL
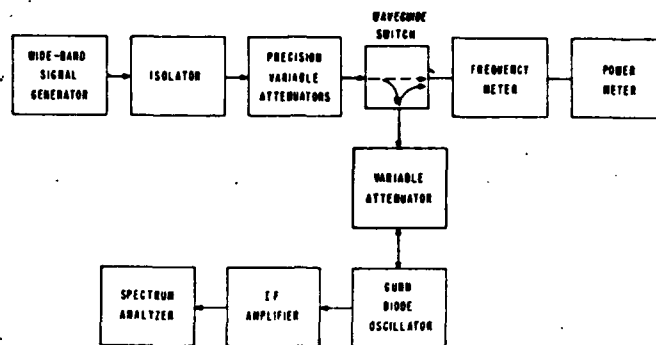
Fig. 9   Block diagram of measurement
          system for minimum detectable
          signal.

GaAs Gunn Diode Imbedded In
Dielectric Cavity
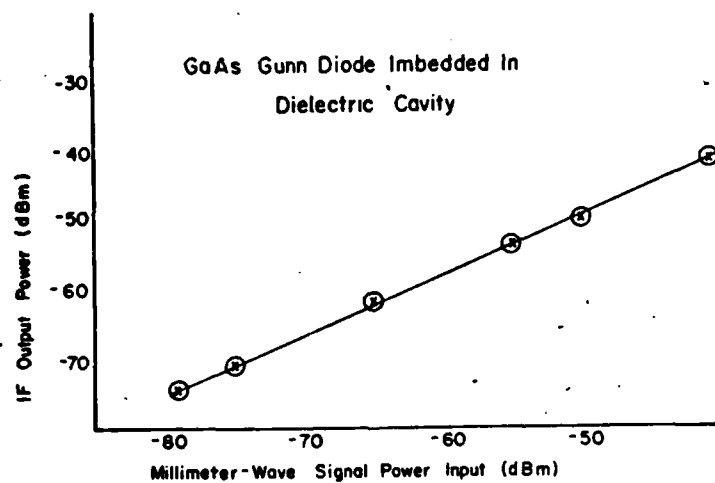
Fig. 10   IF output versus signal power
           for GaAs diode in image guide.
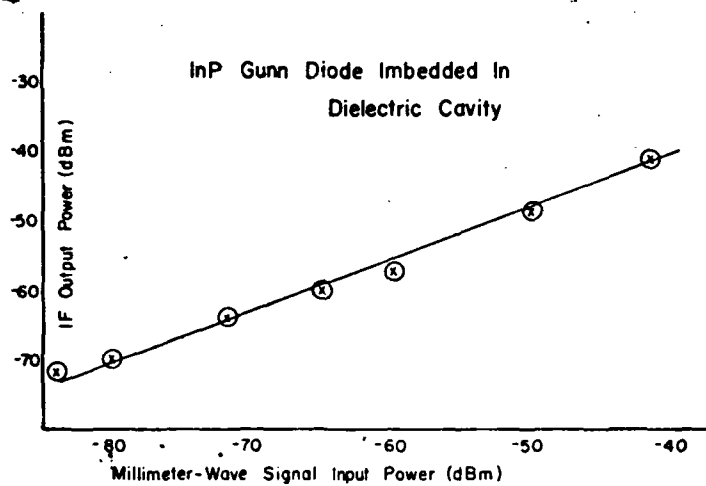
Fig. 11   IF output versus signal power
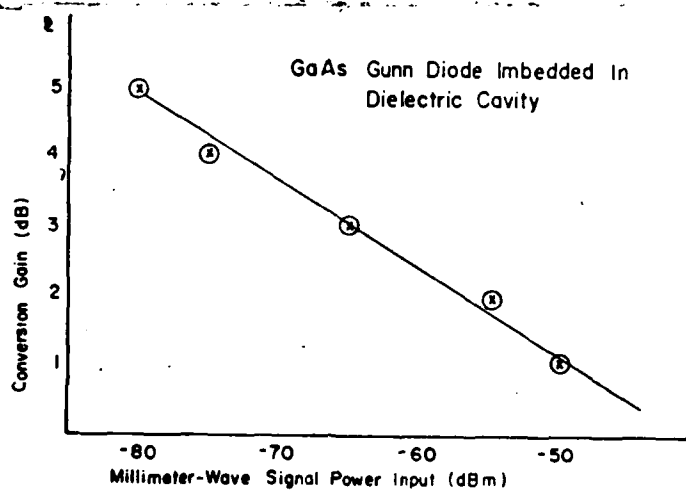for InP diode in image guide.

Fig. 12   Conversion gain versus signal
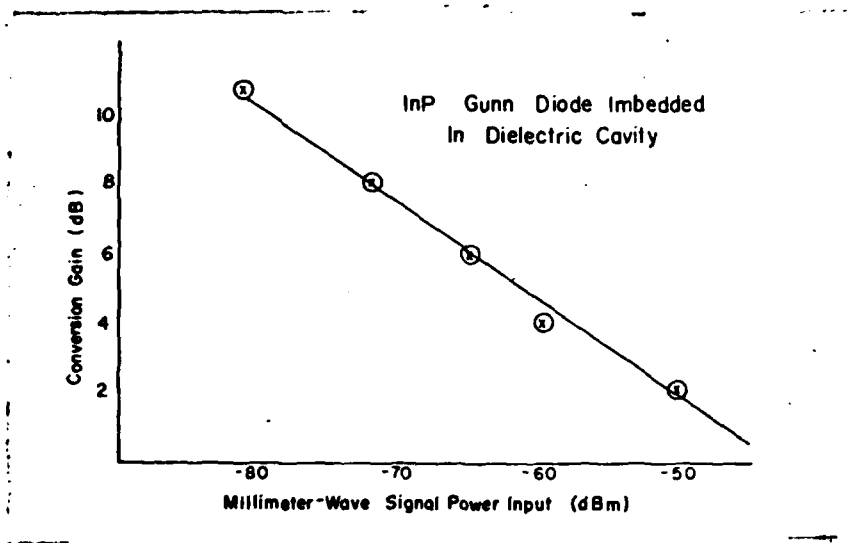power for GaAs diode in image
guide.

Fig. 13 Conversion gain versus signal
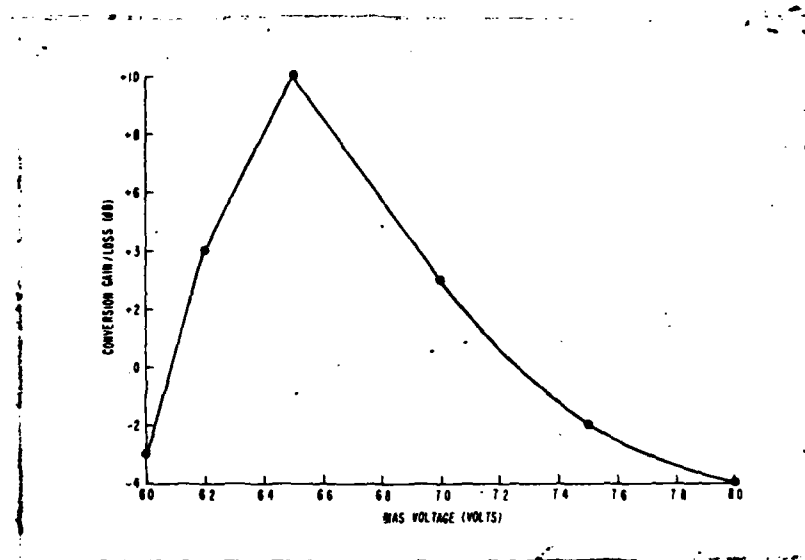power for InP diode in image
guide.

Fig. 14 Conversion gain versus bias
voltage for InP diode in
image guide.

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